A Coupling of the RAMA Fluence Methodology and SCALE Code Packages for Reactor Internals Applications

Activation/Decay, Helium Generation, and Other Applications

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Outline

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The RAMA Fluence Methodology (RAMA) is an EPRI Software Product

- The software is readily available to all members of BWRVIP

Defined Applications for RAMA Include:

- Determination of RPV fast neutron fluence per RG 1.190
- Determination of activation and fluence in surveillance capsule dosimetry
- Determination of dose rates in water for radiolysis

By Coupling RAMA With Other Code Methods, RAMA Can Support:

- Determination of temperatures in components due to radiation heating
- Determination of dose for equipment qualification
- Determination of isotopic activation-decay in irradiated components and structures

Today’s Topic: Helium Production
An Accurate Determination of Helium Production Requires a Comprehensive Set of Reactor Materials and the Associated Activation/Depletion/Decay Chain Sets for Helium Generation

The RAMA Software Can Calculate Simple Helium Production Rates

- RAMA was developed as a fluence calculator and lacks sufficient nuclear data to make an accurate determination of helium production

Introduce the SCALE Software Package, and Specifically ORIGEN

- ORIGEN is a standalone code for calculating activation, decay and depletion

Coupling RAMA’s Detailed Neutron Flux Solutions With ORIGEN’s Detailed Activation and Decay Calculations Provides an Accurate and Detailed Solution for Determining Helium Production Throughout the Reactor System
The Determination of Helium Production in Reactor Materials Requires Detailed Neutron Flux Information

Determining Accurate and Reliable Neutron Flux Throughout the Reactor System Requires the Use of Highly Complex Models

- Reactor cores come in a variety of configurations
- Fuel assemblies come in a variety of designs
  - BWRs – 8x8, 9x9, 10x10, water tubes, water boxes, water crosses, etc.
  - PWRs – 14x14, 15x15, 17x17, guide tubes, etc.
- Structural components come in a variety of shapes and configurations
  - Rectangular, cylindrical, conical, toroidal, etc.

The RAMA Fluence Methodology Was Designed Specifically to Handle These Needs and Requirements
RAMA is a Full, 3D Modeling System Based on Integral Transport Theory

- 3D generalized modeling based on combinatorial geometry techniques
- 3D method of characteristics with anisotropy
- Accurate and predictable results
- Does NOT require adjustments for, e.g., the Albedo Effect

Detailed Models Have Been Constructed for 25+ BWRs and PWRs

RAMA’s Overall C/M is $1.01 \pm .08$ (Unadjusted)

- Determined from over 1,100 dosimetry and experimental measurements
RAMA Meets the Requirements of RG 1.190

RAMA Has Received 3 Safety Evaluation Reports (SERs) from the NRC

- It is generically approved for determining RPV fluence in BWRs and PWRs with ZERO bias
- It is also approved for determining fluence in RPV internals
  - Core shrouds
  - BWR top guides
Examples of BWR Models

BWR Shroud Internals (Shroud Head, Stand Pipes, Spargers, Top Guide, Core Support Plate, Fuel Supports, and Rim Bolts)

BWR Jet Pumps and Riser Brace Assemblies

BWR Core Support Plate, Fuel Supports, Control Rods and Rim Bolts

BWR Vessel W/ Nozzles (View from the Cavity)

BWR Recirc Nozzles

BWR LPCI Coupler
The SCALE-ORIGEN Software

SCALE is a Modeling and Simulation Suite for Nuclear Safety Analysis

SCALE Contains Numerous Computer Codes and Nuclear Data Libraries for Performing a Variety of Nuclear Analyses

ORIGEN is One Software Component of SCALE

ORIGEN Represents the Industry-Standard for Calculating Activation, Decay, and Depletion Effects in Reactor Fuel and Structural Materials

ORIGEN Employs a Point Model Solution, and is Easily Coupled With the Region-Flux Solutions Calculated by a RAMA-type Transport Code

Thus, the Coupling of the RAMA and SCALE-ORIGEN Codes Provide an Elegant and Accurate Approach for Calculating Helium Production
The RAMA-ORIGEN Linkage has been Used to Calculate Helium Production for a Variety of BWR and PWR Systems

Demonstration of the RAMA-ORIGEN Linkage was Presented at PHYSOR 2016 for the Following Plant Configurations:

- BWR – 800 assembly BWR/6, 3833 MW\textsubscript{th}
- PWR – 204 assembly PWR, 2527.73 MW\textsubscript{th}
- PWR – 157 assembly PWR, 2300 MW\textsubscript{th}

The RAMA-ORIGEN Linkage was Used to Determine Helium Production in BWR Systems in Support of BWRVIP-97, Revision 1

- RAMA plant-specific models were used as the basis for the analysis
Helium Production as a Function of Neutron Fluence

Fluence (n/cm$^2$)

Helium Concentration (APPM He)

- Iron
- Chromium
- Boron
- Nickel
- Total
Helium Concentration Profiles

Helium Concentrations at 40 EFPY

Benchmark BWR/6

Benchmark PWR
Benefits

The RAMA Fluence Methodology Is An Accurate Tool for Determining the Spatial and Energy Distribution of Neutron Flux in Reactor Components and Materials

RAMA is Readily Available to All BWRVIP Members

Several Utilities Already Have RAMA Fluence Models, Which Has Additional Benefits

- These models account for the entire operating history of the reactor
- These same models can be used for determining helium content, although an extended energy mesh is required in order to capture thermal neutron effects

RAMA has been Coupled With ORIGEN to Provide an Accurate Process for Determining Helium Concentrations in Reactor Components
Because RAMA Provides a Detailed Modeling System With Demonstrated Accuracy, It is Recognized that RAMA Has Other Uses

Examples:

- RAMA Linked With TRANSFEA to Produce Temperature Profiles in Concrete
- RAMA Linked With MCNP to Generate Dose Rates for Equipment Qualification
- Neutron & Gamma Source Terms Are Calculated With RAMA
- Neutron & Gamma Dose Rates Are Calculated With MCNP
- Total Heating Calculated With RAMA
- Total Neutron Heating
- Total Gamma Heating
- Total Temperatures Calculated With TRANSFEA
Conclusions

The RAMA Fluence Methodology is a Proven 3D Modeling System for Determining Accurate and Predictable Neutron Flux in Nuclear Reactor Pressure Vessels, Vessel Internals, and Surrounding Structures

RAMA has been Approved by the NRC for Determining Fast Neutron Fluence RPVs and Internals

Utilities With Existing RAMA Fluence Models Could Benefit Immediately to Address New Requirements for Evaluating Other Radiation-Important Issues

Coupling of the RAMA-ORIGEN Codes, as Well as the RAMA-MCNP Codes, Provides Robust Solutions for Solving Plant-Specific Radiation Problems

Finally, it is Demonstrated that the Capabilities Exist to Evaluate New and Developing Radiation Issues that Affect Material Integrity Using Accurate, Industry-Leading Radiation Transport, Activation, and Decay Methods
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Questions?